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METALLURGICAL AND FRACTURE STUDIES UNDER WAY IN SOME  
NORTHERN EUROPEAN AND TURKISH ORGANIZATIONS

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METALLURGICAL AND FRACTURE STUDIES UNDER WAY IN  
SOME NORTHERN EUROPEAN AND TURKISH ORGANIZATIONS

I. BACKGROUND

This report contains brief notes relative to fracture studies conducted in various Northern European laboratories visited by the author as an AGARD consultant on electron fractography. Since the primary purpose of the visits was to give rather than to receive information, the notes result from voluntary and generous contribution from the hosts, and consist of whatever subjects that evolved. The notes are therefore by no means complete, even in the selected subject of fracture.

II. THE NETHERLANDS

Pumping water into the Noord and Wadden Zees, and keeping it there, is a continuing and accelerating national purpose; tulips, a few operating windmills, old city gates, walls and churches remind one of the past. Many children still play in wooden shoes - but their fathers are engaged in late 20th century technological problems arising from such things as collecting natural gas from fields in the northeast and the prospects of building a liquid-sodium cooled power reactor in cooperation with neighboring countries. All four laboratories visited in the Netherlands are at least partly supported by the government.

The technological universities are completely and enthusiastically supported by the government. Spacious modern buildings and up-to-the-minute equipment testify to the government's intensive implementation of the belief that the Netherlands' technological future depends upon the production of engineers with knowledge of today's engineering problems and their solutions. The Technische Hogeschool at Delft<sup>(1)</sup> was the first of these universities. One of the government's first steps toward long-term recovery after the second war was the building of more technological universities. These "daughters of Delft" are located at Eindhoven (teaching began in 1967) and Twente T.H. near Enschede (teaching began in 1966). A fourth university is to be located in the Province of North Holland, which is the peninsula immediately north of Amsterdam bounded on the other three sides by the North Sea, Wadden Sea, and the IJsselmeer (the old Zuiderzee).

(A) Eindhoven University

The Metallurgy Department is under Professor J. H. Zaat, who is primarily interested in friction, wear, and lubrication. For these studies they use two techniques: (a) dragging hemispherical metal specimens over another smooth surface, controlling the traverse speed, contact pressure, environment and surface finish. The environment for these tests is air, dried by passing through several columns (about 5 ft tall) of silica gel and then through active carbon; (b) measuring liquid contact angles on clean metal surfaces. New vacuum equipment will give  $10^{-9}$  to  $10^{-10}$ .

(1) J. B. Cohen, ONR London Technical Report ONRL-36-67, 14 June 1967.

torr. Before the liquid is dropped onto the surface, they will clean the surface with electron and ion bombardment.

They use an AEI microprobe, a Metioscope, and a Philips 200 electron microscope to study metal transfer, removal, and smearing during the tests.

Some of the Philips scientists from the nearby Philips electronics research laboratories are part-time professors at the University.

#### Mechanics Department

Headed by Professor W. L. Esmeyer, the Department studies stresses in structures and fatigue crack initiation. Birefringent models, up to one foot wide are used in stress studies in equipment which semi-automatically locates and reads the stress values between fringes. Both the magnitudes and directions of stresses are quickly found.

Rosette strain-gage readings from 50 or more rosettes on structures and structural components are automatically recorded on tape at rates of several readings per second.

The fatigue laboratory has several large fatigue machines, and a large facility for fatigue-testing assembled structures using several Moog-valved electro-hydraulic rams simultaneously. There is also an elaborate photographic system for accurate continuous measurement (about 1/100 mm accuracy) of crack lengths at all four edges of the two cracks in center-cracked fatigue specimens. This is used in tests aimed at establishing a relationship between the stresses found in birefringent models and the initiation of cracks in metal specimens.

#### (B) The Metal Institute, T.N.O., Delft

Presently directed by Cornelis Antonius Verbraak, The Metal Institute was established by law in the 1930's and grew significantly after WW II. It has about 250 people, is (as is all of TNO) non-profit-making, with the government matching funds from large oil companies, metal industries and other private companies. The Metal Institute also receives funds from EURATOM for studies of material problems associated with liquid-sodium fast breeder reactors. The Metal Institute is moving to Appledorn, where some liquid-sodium "loop" research is already going on. They hope to build a reactor in the early 1970's.

Types of fracture testing at The Metal Institute include Robertson, Pellini drop-weight, notched impact (Charpy, DVN, and modified Charpy's), linear elastic fracture analyses, smooth tension and model vessels pressurized with either air or brine at  $-30^{\circ}\text{F}$ . They are limited to 600-tons tensile loading. All the fracture tests are instrumented, with the crack-opening displacement of test pieces being measured over 5 mm across the crack tip. In the Robertson tests they use one test piece to

estimate the crack-arrest temperature (CAT) and then about three others at uniform temperatures to establish the accurate CAT. They have found by experience that  $CAT = NDT + 30^{\circ}F$ . They have mainly been studying ferritic steels, but have also looked at austenitic steels for breeder reactor applications, and some aluminum alloys.

A correlation has been established between the Robertson CAT and energy absorption in "stress-wave attenuation" tests when brittleness is caused by thermal aging. They use this correlation to predict Robertson CAT's from small (about 0.2 cc) attenuation specimens that have been irradiated in reactors. They do not measure the environmental effects upon fracture. They believe that if the arrested crack length (in ductile materials) in the Robertson test is shorter or equal to the crack length in service, the service structure will be subject to failure by unstable fracture.

They use moiré patterns to measure strains, using a "mother" grid to imprint a pattern on the specimen surface, and then placing the "mother" on the specimen surface after fracture to show the degrees of deformation. They evaluate welds using all of the fracture tests. In the near future they will also use vessel-burst tests of welds.

Dr. Van Elst is in charge of most of the work in brittle fracture, but is also doing work on hydrogen containers, magnetization aspects of transformer sheet, ferritic determinations after welding, and internal friction studies.

Verbraak takes personal interest in the electron microscopy.

Dr. De Lange is in charge of the Applied Physical Chemistry Department, and is interested in single crystal growth, electron microscopy, fatigue, stress-corrosion cracking, cathodic etching, creep tests, X-ray spectroscopic analyses, residual stress analyses, diffraction texture analyses, and microprobe techniques. In corrosion he looks with the electron microscope for early direct chemical attack of Cu-Ni-Fe alloy for marine applications. In an austenitic stainless steel he uses successive replicas to look at the initiation and propagation of cracks. Under De Lange, Mr. Drenth is in charge of fatigue tests, and Mr. Zeedijk is in charge of electron and field ion microscopy.

Working directly for Verbraak both at TNO and at the University of Twente is Miss Von Zuylen, who is doing her PhD thesis relating dislocation structures to brittle fracture in low alloy steels. She takes thin foils from just below the fracture surfaces of Robertson test pieces, and using the window technique, has found (1) shock-wave produced dislocations, (2) onset of mechanical twins at and below  $-25^{\circ}C$  in a low carbon steel, and (3) dislocations in contrast when the foil is in the 111 orientation. She has found that the foil must be no more than 0.03 mm from the fracture surface if the fracture-induced dislocations are to be seen.

### III. THE TECHNICAL UNIVERSITY OF DENMARK

The Metallurgy Department is under Professor E. W. Langer, and is at the new University site at Lyngby. The whole University will eventually move from Copenhagen to Lyngby. The Applied Mechanics Department is at Rignsgade 13, Copenhagen, under Professor Frithiof I. Niordson.

#### Metallurgy Department

The Technical University at Lyngby has four main divisions: Electrical, Chemical, Mechanical, and Civil Engineering. The Laboratory for Metallurgy comes under the Chemical Engineering Department. The Rector for the University is E. Knuth-Winterfeldt of electropolishing fame. He has a position in the Metallurgy Department though he is seldom around. The main efforts in research are in corrosion. They have an electron microscope, electron probe, and standard X-ray diffraction units. They have two professors (E. W. Langer and Knuth-Winterfeldt) and six engineers (E. Maahn and H. Barbré in corrosion, K. A. Thorsen in hot cracking of weldments, J. Walker with the electron microscope, P. L. Nielsen with the electron probe, and V. F. Buchwald who studies meteorites and is now in Arizona).

Maahn and Barbré are studying the relationship between location of pits and metallurgical phases when passivation breaks down, with the currents applied via a potentiostat. They are studying Cr-Ni-Fe-Mo alloys where the Cr, Ni, and Fe are kept in the ratio of 20 Cr, 12 Ni, and 68 Fe and the Mo is varied at 5, 10, 15, 20, and 25%. They use solutions containing NaCl and sulphuric acid and vary the pH from 0 to 8.

Nielsen's work with the probe is one half analyses for industry. He has worked with the Danish AEC research station at Roskilde studying the corrosion of Zircaloy and has worked with the Korrosions Centralen in Copenhagen, studying the contents of corrosion pits.

### IV. NORWAY

#### (A) Sentralinstitutt for Industriell Forskning, Blindern, Oslo, Norway.

Metallurgy is one of seven divisions of the Central Institute for Industrial Research, and is headed by Dr. Borge Haigland. The Institute is supported by industrial contracts and by the Royal Norwegian Council for Industrial Research which in turn is partially supported by a national soccer pool. The Central Institute developed a digital control for controlling metal cutting operations in shipyards. The Institute employs about one hundred university graduates.

In metallurgy, N. Ryum has been concentrating on alloy development of hardenable aluminum alloys in the Al-Mg-Zn family, and has been studying the stress-corrosion cracking, brittleness, and welding characteristics as well as the standard mechanical properties of the alloys. However, most of his studies are done with transmission electron microscopy. He has found that



there is a correlation between ductility and the mode of deformation due to the distribution of particles, with the ductility of smooth specimens increasing as the width of the precipitate-free-zone at grain boundaries increases. He hasn't used, and does not plan to use, pre-cracked specimens. Ryum has also studied 1/2 weight percent Zr in Al, in which finely divided  $\text{Al}_3\text{Zr}$  precipitates are formed. These remain stable at temperatures up to  $600^\circ\text{C}$ . Thin-foil studies have shown the reaction: solid solution  $\rightarrow$  simple cubic  $\text{Al}_3\text{Zr}$  as long rods and spheres  $\rightarrow$  (on long aging at high temperatures) tetragonal  $\text{Al}_3\text{Zr}$  in the  $\text{D}_{023}$  space group in the form of needles. The only mechanical tests conducted on this alloy to date are hardness tests, but the alloy may have interesting high-temperature strength properties.

(B) Det Norske Veritas, Department of Materials Engineering and Inspection.

Veritas is mainly concerned with the structural integrity of commercial ships, and exerts a strong world-wide influence upon ship construction. The Department of Materials Engineering and Inspection is one of four primary Departments of Veritas, and is headed by Mr. Herman Wintermark. The main staff consists of some twenty people. There are three principal sections of this Department; welding under Ragnar H. Svik, material approval under Arvid Furuberg and a chemical section under Egil Hekneby. In addition, there are a number of small non-departmentalized groups, such as electron microscopy under Øistein Harsem, who contributed to the French electron fractography handbook.

In the Materialteknisk laboratorium (the materials approval group) they will soon build a 5000-foot-pound Charpy machine (of NRL design) for research into brittleness of welds in carbon steels and in 3-1/2%, 5% and 9% Ni steel for liquid petroleum and liquidized natural-gas-containing ships. This laboratory has routinely used the NDT tests for material approval since 1962. For comparison tests they plan to use the NDT, Robertson, Charpy, Battelle DWT and the NRL "aluminum core test." This research, which is just beginning, is aimed at establishing the "best test" for acceptance of steel from steel companies in Germany and Sweden. (They are also contemplating the use of linear elastic fracture mechanics tests.) Companies in these countries have contributed three batches of steel plate to be used in the comparison tests.

One research effort is aimed at establishing whether or not the present weld-toughness acceptance test is too stringent. They presently use the Charpy criteria for welds as they do for the baseplate.

Another research program just starting is the stress-corrosion cracking of welds in carbon-manganese steels. High manganese and silicon content is suspected to be the reason for severe heat-affected-zone dissolution in sea water of these steels when welded into ship hulls. This group will be using 20 x 30 cm weld-plate specimens attached to the perimeter of a wheel submerged in synthetic sea water. They will not be using pre-cracked specimens, but will be studying the electrochemical potentials of various metallurgical phases in these alloys in synthetic sea water.

(C) Trondheim Technical University

The Metallurgy Department is headed by Professor A. B. Winterbottom. Professor Nils Christensen is head of Metallurgy Division at SINTEF, which is associated with the University in much the same manner as for example DRI is associated with the University of Denver. The staff at the University consists of three professors, one docent (one stage below professor), three metallurgists in charge of laboratories, four scientific assistants (recent graduates), and two technicians. The Metallurgy Department at SINTEF has five metallurgists working under Christensen. B. Augland and Iverson are working on deoxidation of steels. Johannsen is studying carbides of Nb in steels. G. M. Evans is working on hydrogen in steel, and K. Gjermundsen is concerned with analyses of carbon and oxygen in steel.

V. DEUTSCHE VERSUCHSANSTALT FÜR LUFT- UND RAUMFAHRT e. V.; INSTITUT FÜR FESTIGKEIT, MULHEIM-RUHR, GERMANY

Headed by Dr. Kowalevski, this laboratory is mainly interested in strengths of structures. It is similar to NASA Langley but on a much smaller scale. It has four main divisions: a) Stresses in and Stability of Vibrating Structures under Dr. Schiffner (5 graduates); b) the Fatigue Strength Department under Dr. G. Jacoby (3 graduates, seven total); c) Kinetic Heating, under Dr. Kowalevski (2 graduates); and d) Stress Analysis, under Dr. Schwieger. In the Kinetic Heating Department they simulate the aerodynamic heating of structures by infrared radiation, but are more interested in thermally induced stresses than in creep. In Jacoby's Department, there are a number of fatigue machines with which he studies the effects of various programmed loadings upon fatigue crack propagation. Tests are conducted to examine the effects of temperature ( $-70^{\circ}\text{C}$  to  $250^{\circ}\text{C}$ ), environment (humidity), cyclic frequency, and stress levels. Materials studied include aluminum alloys 2024, RR58, 2218, 2219, 2020, SAP, and Al-Ni alloys. The alloy 2218 has a 30% higher fatigue strength than 2024 and a 100% higher life in notched specimen tests. They are studying 2024 plus 2% Ni in several conditions - using different solution temperatures, homogenized versus non-homogenized, extruded, drawn, and recrystallized. They are also studying a Co-Cr-Ni alloy, conducting tests on smooth and notched specimens at both room and elevated temperatures.

Some of the fatigue effects noted by Jacoby are:

- a) Lower frequencies give 25% higher crack propagation rates (growth per cycle) in 2024 aluminum when the frequency was changed from 32 Hz to 1/2 Hz.
- b) Square wave gives more crack growth per cycle than sine or triangular wave (load-time curves) in 2024 aluminum when cycled at 120 cycles per minute.
- c) A decrease in the lives of notched specimens of 2024, RR58, and 2218 (in several heat-treated conditions) with an increase in relative humidity.
- d) Raising the temperature decreases the fatigue life in both smooth and notched specimens.

## VI. MIDDLE EAST TECHNICAL UNIVERSITY, ANKARA, TURKEY

This is a new university located about two miles out of Ankara on the southeast side of town. The Departments in the faculty of Engineering include: Metallurgical, Chemical, Civil, Mechanical, and Mining Engineering. The Metallurgical Engineering Department, headed by Professor Doruk was established in June 1966, having previously been a sub-division of the Mechanical Engineering Department. They have students in the 2nd, 3rd, and 4th year levels, plus a few masters degree students. They have a total of 72 students, with five in graduate work, three in post-graduate work, two at Sheffield University and three in the USA. The scholastic program includes physical, mechanical, and extractive metallurgy. There are six research leaders, Doruk, T. Ogurtani, A. Ankara, Tekin, Rosenquist, and Unckel. Both Rosenquist and Unckel are visiting from other countries (Norway and Germany respectively) to help set up the Department. Most of the research is done in the Physical Metallurgy section under Doruk.

The main research efforts at present are:

- 1) Diffusion of Al in Al-Nb alloys (Ogurtani), with plans for studying the oxidation of these alloys.
- 2) Internal friction measurements in determinations of Young's modulus (Ankara and Ogurtani).
- 3) Corrosion fatigue of mild steel (Doruk). Using smooth rotating-beiding specimens, he has found that the slope of the polarization curve increases with time (or number of cycles) in corrosion fatigue. He now plans to use pure torsion-fatigue loading since he is interested in constant strain amplitude.
- 4) Reverse martensitic transformation as related to superplasticity (Dr. Ankara).
- 5) Doruk has been concerned with trying to find more utilization of Turkish ferro-chromium in electroplating processes. He reports that the coatings produced so far have been crack-free but that the process has not yet been successful on a large scale.

The University has no fracture research under way.

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